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(72)Inventor : SUGIMOTO MITSUNORI

(54) SURFACE-EMISSION LASER AND MANUFACTURE THEREOF

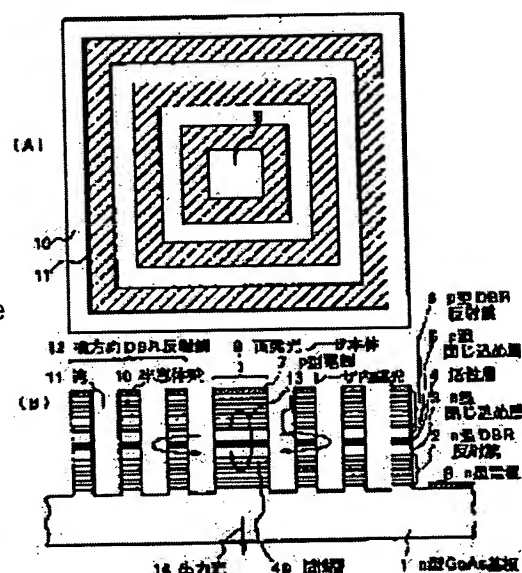
(57)Abstract:

PURPOSE: To enable the operation as a micro-cavity laser on a low current by specifying the thickness of a semiconductor wall and the distance between a semiconductor pillar and the semiconductor wall.

CONSTITUTION: A first DBR reflection film 2 and a multilayer structure, containing a p-n junction and an active layer 4a, are formed on a semiconductor substrate 1.

A second DBR reflection film 6 is formed on the multilayer structure. Then semiconductor pillars, composed of the first DBR reflection film 2, multilayer structure, and second DBR reflection film 6, are formed by dry etching. In addition to the semiconductor pillars, a semiconductor wall 10 containing the semiconductor pillars in the lateral direction, is simultaneously formed by the dry etching.

Letting the medium wavelength of the light emitted from the active layer 4a be λ , the thickness of the semiconductor wall 10 and the distance between the semiconductor pillar and wall 10 are both specified as approx. $\lambda/4+2$ (integer multiple of $\lambda/2$). In case there are two or more semiconductor walls 10, their interval is specified as approx. $\lambda/4+(\text{integer multiple of } \lambda/2)$.



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CLAIMS

[Claim(s)]

[Claim 1] The 1st DBR reflective film formed on the semi-conductor substrate, and the PN junction formed on this 1st DBR reflective film and multilayer structure containing a barrier layer, The semi-conductor column which consists of 2nd DBR reflective film formed on said multilayer structure, and said 1st DBR reflective film and said multilayer structure, and said 2nd DBR reflective film, When setting to λ wavelength in a medium of the light which is equipped with at least one semi-conductor wall formed in this semi-conductor column so that a longitudinal direction might be surrounded, and carries out outgoing radiation from said barrier layer, The surface emission-type laser to which said two or more semi-conductor walls are characterized by the spacing being $\lambda / 4 + (\lambda/2 \text{ of integral multiples})$ mostly by the thickness of said semi-conductor wall and spacing between said semi-conductor columns and said semi-conductor walls being $\lambda / 4 + (\lambda/2 \text{ of integral multiples})$ mostly, respectively in a certain case.

[Claim 2] The process which forms the 1st DBR reflective film on a semi-conductor substrate by carrying out the laminating of the semi-conductor layer from which a refractive index differs by turns, The process which forms the multilayer structure containing a PN junction and a barrier layer on this 1st DBR reflective film, The process which forms the 2nd DBR reflective film on this multilayer structure by carrying out the laminating of the semi-conductor layer from which a refractive index differs by turns, By this dry etching that forms half-**** which consists of said 1st DBR reflective film and said multilayer structure, and said 2nd DBR reflective film by dry etching When setting to λ wavelength in a medium of the light which is equipped with the process which forms in said semi-conductor column and coincidence at least one semi-conductor wall which surrounds this semi-conductor column in a longitudinal direction, and carries out outgoing radiation from said barrier layer, The manufacture approach of the surface emission-type laser characterized by two or more semi-conductor walls making [for the thickness of said semi-conductor wall, and spacing between said semi-conductor columns and said semi-conductor walls] the spacing mostly $\lambda/4 + (\lambda/2 \text{ of integral multiples})$ as $\lambda/4 + (\lambda/2 \text{ of integral multiples})$, respectively in a certain case.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Industrial Application] This invention relates to the micro cavity laser with which a surface emission-type laser, especially an efficient field radiant power output are obtained, and its manufacture approach.

[0002]

[Description of the Prior Art] Research and development is done that the field luminescence laser in which two-dimensional integration is possible is required, and briskly [fields, such as optical exchange, an optical computer, and optical information processing,]. The example is indicated by applied FIJIKUSU Letters (Applied, Physics, Letters) 57 volume 1605-1607 page (1990) by R.S.Geels, L.A.Coldren and others. In this paper, it is reported that R.S.Geels and others was oscillated by the threshold current of 0.7mA in the surface emission-type laser of 7-micrometer angle.

[0003]

[Problem(s) to be Solved by the Invention] However, in a future optical integrated circuit, in order to integrate a majority of 1000 or more surface emission-type lasers, much more low threshold-ization is required. this demand -- receiving -- recently and a minute resonator -- laser -- a concept is proposed and examination is advanced. for example, Yokoyama -- Journal of Applied Physics 61st -- in the volume ** 9 No. 890-901 page (1992) report, the light in the barrier layer used as a luminous layer is described about possibility of carrying out laser actuation by μ A grade in the laser of the structure which confines all the magnitude of length, width, and the height direction in about one wave. In this laser, the optical output equivalent to a laser beam has been obtained by the very small threshold current by confining light in a very small barrier layer by making the mode consistency of light extremely small and enlarging extremely coupling effectiveness to the cavity mode of spontaneous emission light (- 1).

[0004] However, when such laser (here, it is called micro cavity laser) was manufactured, there was a problem that it was difficult to confine light in a small barrier layer. For example, in the direction of thickness of a barrier layer, the DBR reflective film with a high reflection factor can be formed by carrying out crosswise lamination of the two semi-conductor layers from which a refractive index differs. For this reason, slight closing depth of the light of a lengthwise direction (the direction of thickness) can be realized comparatively easily. However, the slight closing depth of the light of the longitudinal direction of a barrier layer had the problem that implementation was difficult. For example, also when a reflection factor formed the reflective film of the gold which is about 90%, there was a problem that a reflection factor was not sufficiently high. Moreover, when the DBR reflective film was formed in a longitudinal direction, there was a problem with it difficult [to control correctly the thickness in a side face which formed membranes].

[0005] Then, since the slight closing depth of a strong light of not only a lengthwise direction (the direction of thickness) but a longitudinal direction is possible for the purpose of this invention, it offers the field luminescence laser which can be operated as micro cavity laser by low current, and its manufacture approach.

[0006]

[Means for Solving the Problem] The 1st DBR reflective film formed on the semi-conductor substrate in the surface emission-type laser of this invention, The PN junction formed on this 1st DBR reflective film, and the multilayer structure containing a barrier layer, The semi-conductor column which consists of 2nd DBR reflective film formed on said multilayer structure, and said 1st DBR reflective film and said multilayer structure, and said 2nd DBR reflective film, When setting to λ wavelength in a medium of the light which is equipped with at least one semi-conductor wall formed in this semi-conductor column so that a longitudinal direction might be surrounded, and carries out outgoing radiation from said barrier layer, The thickness of said semi-conductor wall and spacing between said semi-conductor columns and said semi-conductors are $\lambda/4 + (\lambda/2 \text{ of integral multiples})$ mostly, respectively, and, in a certain case, said two or more semi-conductor walls are characterized by the spacing being $\lambda/4 + (\lambda/2 \text{ of integral multiples})$ mostly.

[0007] The process which forms the 1st DBR reflective film on a semi-conductor substrate by the manufacture approach of the surface emission-type laser of this invention by carrying out the laminating of the semi-conductor layer from which a refractive index differs by turns, The process which forms the multilayer structure containing a PN junction and a barrier layer on this 1st DBR reflective film, The process which forms the 2nd DBR reflective film on this multilayer structure by ** which carries out the laminating of the semi-conductor layer from which a refractive index differs by turns, By the process which forms the semi-conductor column which consists of said 1st DBR reflective film and said multilayer structure, and said 2nd DBR reflective film by dry etching, and this dry etching When setting to λ wavelength in a medium of the light which is equipped with the process which forms in said semi-conductor column and coincidence at least one semi-conductor wall which is ** which surrounds a longitudinal direction for this semi-conductor column, and carries out outgoing radiation from said barrier layer, It is characterized by a semi-conductor wall making [for the thickness of said semi-conductor wall, and spacing between said semi-conductor columns and said semi-conductor walls] the spacing mostly $\lambda/4 + (\lambda/2 \text{ of integral multiples})$ on two as $\lambda/4 + (\lambda/2 \text{ of integral multiples})$, respectively in a certain case.

[0008]

[Function] In this invention, the DBR reflective film which consists of crosswise lamination of the semi-conductor with which two refractive indexes differ like the surface emission-type laser of the former [shut / the light of the direction of thickness of a barrier layer] was formed in the both sides of a barrier layer, and light is shut up.

[0009] By on the other hand arranging the wall of semi-conductor multilayers regularly the light of the longitudinal direction of a barrier layer shutting up, semi-conductor multilayers and the DBR reflective film effectual between air were formed, and light is shut up. In this case, the refractive index of the refractive index of a semi-conductor is usually before and after three, since a refractive index is 1, the refractive-index difference of air is larger than the DBR reflective film of a semi-conductor, and the DBR reflective film of a high reflection factor can be formed easily. For example, even when a reflection factor R is estimated using the effective refractive index of a semi-conductor wall as 3.25, and the number of semi-conductors is one, it turns out that 98.9% and a semi-conductor wall become 99.9% in three, and a semi-conductor wall is acquired for them by two 89% by the DBR reflective film of number of sheets with few very high reflection factors.

[0010] Moreover, in manufacture of this DBR reflective film, it is not an approach by membrane formation like the conventional DBR reflective film, and the semi-conductor column used as a luminous layer and the semi-conductor wall which forms the DBR reflective film are collectively formed by etching the semiconducting crystal containing a barrier layer by the approach using dry etching. Since it was difficult to control a lateral membrane formation rate by the approach by the conventional membrane formation to a precision, it was difficult to form the DBR reflective film by which thickness control was carried out enough. However, according to the manufacture approach of the DBR reflective film by this invention, the semi-conductor wall used as the semi-conductor column used as a part for a light-emitting part and the DBR reflective film can be formed with a sufficient controllability by using the dry etching excellent in perpendicular etching.

[0011]

[Example] Next, the example of this invention is explained to a detail using a drawing.

[0012] Drawing 1 shows the structure of the surface emission-type laser of the 1st example of this invention. Drawing 1 (A) shows a top view and drawing 1 (B) shows a sectional view. For the inside of drawing, and 1, an n mold GaAs substrate and 2 are the n mold DBR reflective film (for n-GaAs/n-AlAs multilayers and thickness, $\lambda/4$ and λ are the medium wavelength of oscillation light.). For example, in the case of 980nm design vacuum wavelength, it is set to $dGaAs = 69.53nm$ and $dAlAs = 82.94nm$. Although a reflection factor becomes large so that many, periodicity typically 15 to 30 period and 3 n mold confining layer (0-1, preferably [n-AlGaAs and aluminum presentation] 0.2 -0.5), 4 and 4a -- a barrier layer (10nm in thickness [An InGaAs single quantum well, In presentation = 0.1 - 0.3, typically 0.2]) -- 4a shows the barrier layer of a surface emission-type laser body here -- In slight p mold closing depth, 5 is a layer (0-1, preferably [p-AlGaAs and aluminum presentation] 0.2 -0.5), and 6 is the p mold DBR reflective film (for p-GaAs/p-AlAs multilayers and thickness, $\lambda/4$ and λ are the medium wavelength of oscillation light.). For example, in the case of 980nm design vacuum wavelength, it is set to $dGaAs = 69.53nm$ and $dAlAs = 82.94nm$. Although a reflection factor becomes large so that many, periodicity typically For p mold electrode and 8, n mold electrode and 9 are [15 to 30 period, and 7] a surface emission-type laser body (width of face of 10 micrometers or less). 0.25-2 micrometers and 10 are a semi-conductor wall (here, width-of-face - $3\lambda/4$ of 980nm, for example, vacuum design wavelength) preferably. In the case of an effective refractive index 3.21, as for 229nm and 11, a slot (here, set to 245nm at a case with width-of-face - $\lambda/4$ of 980nm, for example, vacuum design wavelength) and 12 are longitudinal direction DBR reflecting mirrors. Here, let thickness which totaled n mold confining layer 3, the barrier layer 4, and p mold confining layer 5 be $\lambda/2$ of integral multiples. For example, in such total thickness, in setting λ and design vacuum wavelength to 980nm and setting a barrier layer 4 to In_{0.2}Ga_{0.8}As of 10 thickness, n mold confining layer 3 and p mold confining layer 5 which consist of aluminum_{0.25}Ga_{0.75}As are respectively set to 140.5nm. Here, the configuration of the surface emission-type laser body 9 or the semi-conductor wall 10 is made into the rectangle.

[0013] In the laser structure of this 1st example, the light generated from barrier layer 4a of the surface emission-type laser body 9 has the structure where the n mold DBR reflective film 2 and the p mold DBR reflective film 6 shut up light to a lengthwise direction (the direction of thickness), and the longitudinal direction DBR reflecting mirror 12 shuts up light to a longitudinal direction. By the DBR reflective film of a lengthwise direction, reflection factors differ by doping concentration or periodicity. As an example, the calculated value of a reflection factor is 99.86% by periodicity 20 and the n mold GaAs/AlAsDBR reflective film of concentration-of-electrons $10^{18} cm^{-3}$. Moreover, periodicity 20 and electron hole concentration $10^{18} cm^{-3}$ By the p mold GaAs/AlAsDBR reflective film, the calculated value of a reflection factor becomes 99.77%.

[0014] Moreover, on the other hand in the DBR reflecting mirror 12 of the longitudinal direction of three periods as shown in drawing 1, the calculated value of a reflection factor becomes 99.90%. Moreover, when the lateral DBR reflecting mirrors 12 are two periods, 98.9% of reflection factors is expected. Thus, with the longitudinal direction DBR reflecting mirror 12, since the refractive-index difference of air and a semi-conductor is large, a big reflection factor is obtained by small periodicity.

[0015] As stated above, since both a lengthwise direction and a longitudinal direction are surrounded with the DBR reflecting mirror of 99% or more of reflection factor, in the surface emission-type laser of this example, the interior light 13 of laser is efficiently shut up, as an arrow head shows to drawing 1. such a good light -- shutting up -- the mode consistency of light decreases and the output light 14 with the sharp wavelength spectrum which resembled the laser beam in the low current impregnation field 1mA or less according to the micro cavity effectiveness, or radiation directivity is obtained.

[0016] Since there is little mode which emits light in a longitudinal direction for the light of wavelength λ when making width of face of the surface emission-type laser body 9 into $\lambda/2$ of nonintegral twice especially, luminescence of lateral spontaneous emission is controlled. To the mode of a lengthwise direction, by making thickness of the sum total of n mold confining layer 3, a barrier

layer 4, and p mold confining layer 5 into $\lambda/2$ of integral multiples, luminescence of a lengthwise direction will be in a resonance state, and is promoted. For this reason, in order that the optical output of spontaneous emission light may concentrate only on a lengthwise direction, as for the ejection effectiveness of the output light 14, unlike the conventional LED luminescence, 10% or more of very high effectiveness is expected. On the other hand, in the conventional LED, since the light from a barrier layer was emitted isotropic, the ejection effectiveness of light was as low as at most about 1%.

[0017] If the improvement which reduces enough the breathing-loss reduction to the interior light 13 of laser and the nonluminescent recombination of the carrier poured into barrier layer 4a can be made in coincidence besides the improvement which light which was described above shuts up, also in the very low current field of μA order, concentration of spontaneous-emission light takes place to a lengthwise direction, and the output light 14 which has a sharp wavelength spectrum similar to a laser beam and radiation directivity can be efficiently obtained to it. Furthermore, the usual laser oscillation is obtained in the high current impregnation field which raised current impregnation.

[0018] Next, the manufacture approach of the surface emission-type laser of the 1st example is explained. First, sequential growth of the n mold DBR reflective film 2, n mold confining layer 3, a barrier layer 4, p mold confining layer 5, and the p mold DBR reflective film 6 is carried out with MBE growth on the n mold GaAs substrate 1. Next, p mold electrode 7 is formed on the p mold DBR reflective film 6. Next, using the dry etching method, by forming a slot 11, the surface emission-type laser body 9 and the semi-conductor wall 10 are separated, and the longitudinal direction DBR reflecting mirror 12 is formed. The chemical reed SUTEDDO ion-beam-etching method (CAIBE law) which uses as a reaction kind the reactant ion-beam-etching method (RIBE law) using the ECR plasma and argon ion of the chlorine which uses a chlorine radical and a chlorine ion as a reaction kind, and chlorine gas as dry etching in this case can be used. especially -- CAIBE -- the NiAu film of this p mold electrode 7 when using law by dry etching, after carrying out patterning of the nickel/Au film with a lift-off technique and forming p mold electrode 7 -- CAIBE -- since it can use as mask material in the case of the dry etching by law, a detailed pattern can be formed easily. Next, n mold electrode 8 is formed. It is made thin by polish mechanical to the thickness of a request of the n mold GaAs substrate 1 at the last.

[0019] Drawing 2 is the sectional view of the surface emission-type laser of the 2nd example. Most laser structures of this example are the same as the 1st example. A different point is a point that the slot 11 is filled up with polyimide 20. In the 2nd example, since flattening of the p side front face is carried out with polyimide 20, there is an advantage which can form the drawer electrode 21 easily. Moreover, in order to consider as $\lambda/4$, it is necessary to make width of face of a slot 11 into (the refractive index of 1-/polyimide) of the width of face of the slot 11 in the 1st example. Moreover, the manufacture approach of the 2nd example is almost the same as the 1st example too. A different point is performing patterning for forming spreading of polyimide 20, and opening of the drawer electrode 21 and opening of n mold electrode 8 after dry etching.

[0020] In the above example, although the barrier layer was made into the single quantum well, not only this but a multiplex quantum well and a thick barrier layer 20nm or more may be used. Moreover, although thickness which doubled n mold confining layer, p mold confining layer, and the barrier layer was set to λ , thickness can be changed if it is the integral multiple of not only this but $\lambda/2$. Moreover, as an ingredient, although the GaAs/AlAs system ingredient was used, it can use, not only this but other semiconductor materials, for example, InP/InGaAs system ingredient etc., etc. moreover -- although the slot was embedded in the 2nd example using polyimide -- not only this but other dielectric materials 2, for example, SiO, etc. -- you may use. Moreover, with the top view of an example, although the lateral DBR reflecting mirror was formed with the square, it is good not only as for this but a round shape etc.

[0021] Moreover, although semi-conductor wall thickness was set to $3\lambda/4$ in the example, what is necessary is just thickness generally expressed in writing by $\lambda/4 + (\lambda/2 \text{ of integral multiples})$, such as not only this but $\lambda/5$ [$4\lambda/5$ and $3\lambda/4$], etc. However, it becomes being $\lambda/4$ of thickness with the thickness of about 60nm, and a semi-conductor wall becomes easy to collapse. When there is such a problem, it is good to establish the reinforcement semi-conductor wall 30

which connects semi-conductor walls, as shown in the top view shown in drawing 3 . Moreover, although width of face of a slot 11 was made into $\lambda/4$ in the example, what is necessary is just the width of face not only in this but generally expressed in writing by $\lambda/4 + (\lambda/2 \text{ of integral multiples})$.

[0022]

[Effect of the Invention] According to this invention, since light can be efficiently confined not only in a lengthwise direction but in a longitudinal direction, an optical mode consistency can be made small and the surface emission-type laser from which the output light which has the sharp wavelength spectrum and the directivity like a laser beam according to the micro cavity effectiveness in a low current region is obtained can be realized.

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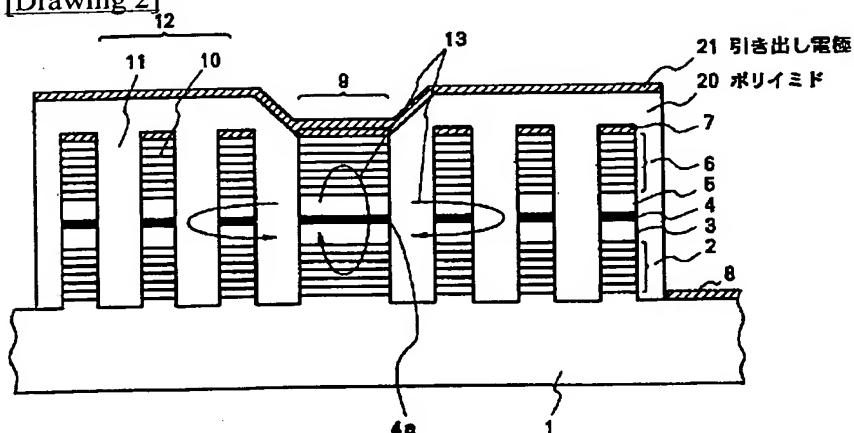
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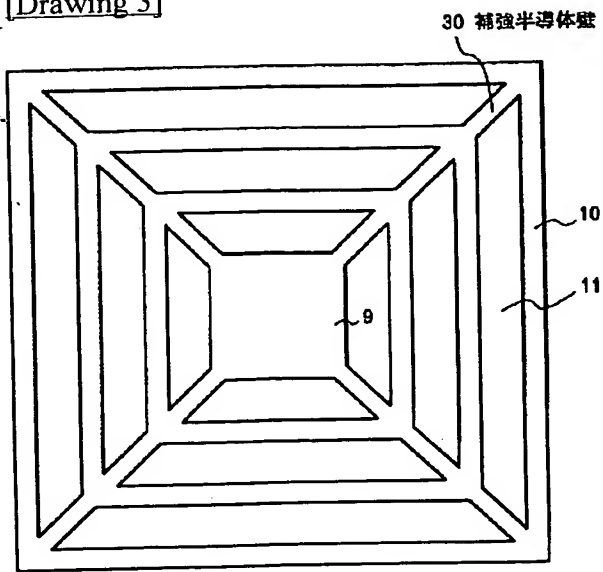
[Drawing 1]



[Drawing 2]



[Drawing 3]



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Patent Abstracts of Japan

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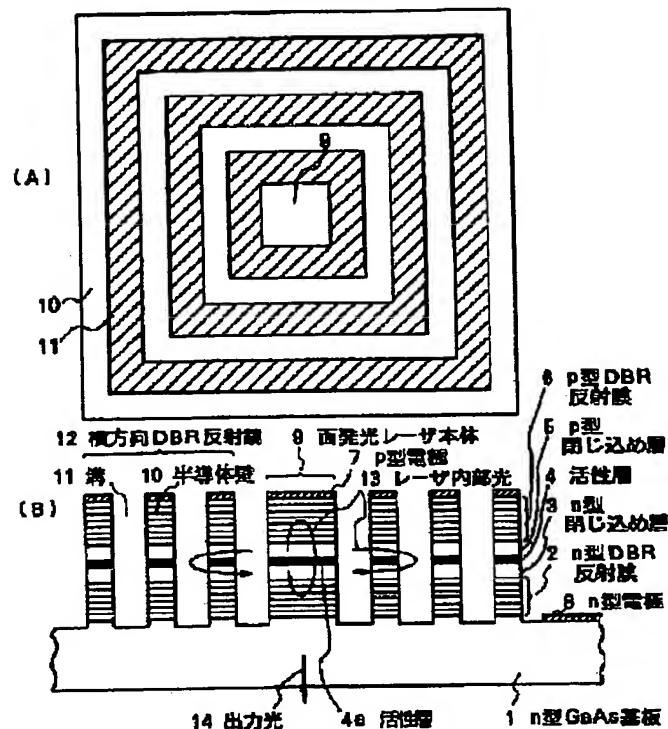
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APPLICANT : NEC CORP;

INVENTOR : SUGIMOTO MITSUNORI;

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TITLE : SURFACE-EMISSION LASER AND
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ABSTRACT : PURPOSE: To enable the operation as a micro-cavity laser on a low current by specifying the thickness of a semiconductor wall and the distance between a semiconductor pillar and the semiconductor wall.

CONSTITUTION: A first DBR reflection film 2 and a multilayer structure, containing a p-n junction and an active layer 4a, are formed on a semiconductor substrate 1. A second DBR reflection film 6 is formed on the multilayer structure. Then semiconductor pillars, composed of the first DBR reflection film 2, multilayer structure, and second DBR reflection film 6, are formed by dry etching. In addition to the semiconductor pillars, a semiconductor wall 10 containing the semiconductor pillars in the lateral direction, is simultaneously formed by the dry etching. Letting the medium wavelength of the light emitted from the active layer 4a be λ , the thickness of the semiconductor wall 10 and the distance between the semiconductor pillar and wall 10 are both specified as approx. $\lambda/4+2$ (integer multiple of $\lambda/2$). In case there are two or more semiconductor walls 10, their interval is specified as approx. $\lambda/4+(\text{integer multiple of } \lambda/2)$.

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(71) 出願人 000004237

日本電気株式会社

東京都港区芝五丁目7番1号

(72) 発明者 杉本 満則

東京都港区芝五丁目7番1号日本電気株式会社内

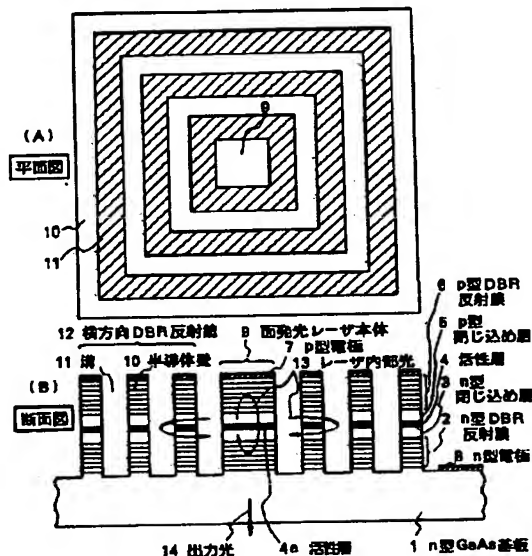
(74) 代理人 弁理士 京本 直樹 (外2名)

(54) 【発明の名称】 面発光レーザとその製造方法

(57) 【要約】

【目的】 低電流域で、自然放出光を効率良く出力できる面発光レーザを提供する。

【構成】 半導体壁10を周期的に配置する事によって、横方向DBR反射鏡12を形成する。この横方向DBR反射鏡12によって、横方向のレーザ内部光13を効率良く閉じ込める事が出来る。また、横方向の光に対して、非共鳴状態にした場合には、横方向の自然放出光の発光が抑制される。従って、横方向のみに、自然放出光を効率良く取り出す事が出来る。また、従来の誘電体膜の成膜に代えて垂直ドライエッチングを用いると、横方向DBR反射鏡12を制御性良くできるため、反射鏡の高い横方向DBR反射鏡12が実現できる。



【特許請求の範囲】

【請求項1】 半導体基板上に形成された第1DBR反射膜と、この第1DBR反射膜上に形成されたPN接合と活性層を含む多層構造と、前記多層構造上に形成された第2DBR反射膜と、前記第1DBR反射膜と前記多層構造と前記第2DBR反射膜からなる半導体柱と、この半導体柱を横方向に囲むように形成された少なくとも1つの半導体壁とを備え、前記活性層から出射する光の媒質内波長を入とすると、前記半導体壁の厚み、前記半導体柱と前記半導体壁の間隔がそれぞれほぼ $\lambda/4 + (\lambda/2 \text{の整数倍})$ となっており、前記半導体壁が2つ以上ある場合には、その間隔がほぼ $\lambda/4 + (\lambda/2 \text{の整数倍})$ となっていることを特徴とする面発光レーザ。

【請求項2】 半導体基板上に、屈折率の異なる半導体層を交互に積層することによって第1DBR反射膜を形成する工程と、この第1DBR反射膜上にPN接合と活性層を含む多層構造を形成する工程と、この多層構造上に屈折率の異なる半導体層を交互に積層することによって第2DBR反射膜を形成する工程と、前記第1DBR反射膜と前記多層構造と前記第2DBR反射膜からなる半導体柱をドライエッチングによって形成する、このドライエッチングによって、前記半導体柱と同時に、この半導体柱を横方向に囲むような少なくとも1つの半導体壁を形成する工程とを備え、前記活性層から出射する光の媒質内波長を入とすると、前記半導体壁の厚み、前記半導体柱と前記半導体壁の間隔をそれぞれほぼ $\lambda/4 + (\lambda/2 \text{の整数倍})$ として、また、半導体壁が2つ以上ある場合には、その間隔をほぼ $\lambda/4 + (\lambda/2 \text{の整数倍})$ とすることを特徴とする面発光レーザの製造方法。

【発明の詳細な説明】

【0001】

【産業上の利用分野】 本発明は、面発光レーザ、特に高効率の面発光出力が得られるマイクロキャビティレーザ及びその製造方法に関する。

【0002】

【従来の技術】 光交換、光コンピュータ、光情報処理等の分野では2次元集積化が可能な面発光レーザが必要であり盛んに研究開発されている。その一例が、R. S. GeelsとL. A. Coldrenらによって、アプライドフィジクスレターズ (Applied, Physics, Letters) 57巻1605-1607頁 (1990年) に記載されている。この論文において、R. S. Geelsらは7 μ m角の面発光レーザにおいて閾値電流0.7mAで発振したと報告している。

【0003】

【発明が解決しようとする課題】 しかしながら、将来の光集積回路において、1000個以上の多数の面発光レーザを集積化するためには、より一層の低閾値化が要求

される。この要求に対して、最近、微小共振器レーザなる概念が提案され、検討が進められている。例えば、横山は、応用物理学会誌第61巻第9号890-901頁 (1992年) の記事において、発光層となる活性層での光を縦、横、高さ方向の大きさを全て1波長程度に閉じこめる構造のレーザにおいて、 μ A程度でレーザ動作する可能性について述べている。このレーザにおいては、非常に小さな活性層に光を閉じこめる事によって光のモード密度を極端に小さくして、自然放出光のキャビティモードへのカップリング効率を極めて大きく (〜1) する事によって、極めて小さな閾値電流でレーザ光と同等な光出力を得ている。

【0004】 しかしながら、このようなレーザ (ここではマイクロキャビティレーザと呼ぶ) を製作する場合、小さな活性層に光を閉じこめる事が困難であるという問題があった。例えば、活性層の層厚方向では、屈折率の異なる2つの半導体層を交互積層する事によって、反射率の高いDBR反射膜を形成する事が出来る。このため、縦方向 (層厚方向) の光の閉じこめは比較的容易に実現できる。しかしながら、活性層の横方向の光の閉じこめは、実現がむずかしいという問題があった。例えば、反射率が90%程度の金の反射膜を形成する場合にも、反射率が充分高くないという問題があった。また、横方向にDBR反射膜を成膜する場合においても、側面での成膜した厚さを正確に制御する事が困難な問題があった。

【0005】 そこで、本発明の目的は、縦方向 (層厚方向) のみならず、横方向の強い光の閉じこめが可能となるため、低電流でマイクロキャビティレーザとして動作する事が可能な面発光レーザとその製造方法を提供するものである。

【0006】

【課題を解決するための手段】 本発明の面発光レーザにおいては、半導体基板上に形成された第1DBR反射膜と、この第1DBR反射膜上に形成されたPN接合と活性層を含む多層構造と、前記多層構造上に形成された第2DBR反射膜と、前記第1DBR反射膜と前記多層構造と前記第2DBR反射膜からなる半導体柱と、この半導体柱を横方向に囲むように形成された少なくとも1つの半導体壁とを備え、前記活性層から出射する光の媒質内波長を入とすると、前記半導体壁の厚み、前記半導体柱と前記半導体壁の間隔がそれぞれほぼ $\lambda/4 + (\lambda/2 \text{の整数倍})$ となっており、前記半導体壁が2つ以上ある場合には、その間隔がほぼ $\lambda/4 + (\lambda/2 \text{の整数倍})$ となっていることを特徴とする。

【0007】 本発明の面発光レーザの製造方法では、半導体基板上に、屈折率の異なる半導体層を交互に積層することによって第1DBR反射膜を形成する工程と、この第1DBR反射膜上にPN接合と活性層を含む多層構造を形成する工程と、この多層構造上に屈折率の異なる

半導体層を交互に積層する異によって第2 DBR 反射膜を形成する工程と、前記第1 DBR 反射膜と前記多層構造と前記第2 DBR 反射膜からなる半導体柱をドライエッチングによって形成する工程と、このドライエッチングによって、前記半導体柱と同時に、この半導体柱を横方向を囲むような少なくとも1つの半導体壁を形成する工程とを備え、前記活性層から出射する光の媒質内波長を入とすると、前記半導体壁の厚み、前記半導体柱と前記半導体壁の間の間隔をそれぞれ $\lambda/4 + (\lambda/2 \text{ の整数倍})$ として、また、半導体壁が2つ上ある場合には、その間隔を $\lambda/4 + (\lambda/2 \text{ の整数倍})$ とすることを特徴とする。

【0008】

【作用】本発明では、活性層の層厚方向の光の閉じ込めには、従来の面発光レーザと同様に2つの屈折率の異なる半導体の交互積層からなるDBR 反射膜を活性層の両側に形成して光を閉じ込めている。

【0009】一方、活性層の横方向の光の閉じ込めには、半導体多層膜の壁を規則正しく配置する事によって、半導体多層膜と空気の間で実効的なDBR 反射膜を形成して、光を閉じ込めている。この場合に、半導体の屈折率は通常屈折率が3前後であり、空気は屈折率が1であるので、屈折率差が半導体のDBR 反射膜よりも大きく、容易に高反射率のDBR 反射膜を形成できる。例えば、半導体壁の実効屈折率を3.25として、反射率Rを見積ると、半導体壁が1つの場合でも89%、半導体壁が2つでは98.9%、半導体壁が3つでは99.9%となつて、極めて高い反射率が少ない枚数のDBR 反射膜で得られる事が判る。

【0010】また、このDBR 反射膜の製作では、従来のDBR 反射膜の様な成膜による方法ではなく、ドライエッチングを用いた方法によって、活性層を含む半導体結晶をエッチングする事によって、発光層となる半導体柱と、DBR 反射膜を形成する半導体壁を一括して形成してしまうものである。従来の成膜による方法では、横方向の成膜速度を精密に制御する事が困難であるために、充分膜厚制御されたDBR 反射膜を形成する事が困難であった。しかしながら、本発明によるDBR 反射膜の製作方法によれば、垂直エッチングに優れたドライエッチングを用いる事によって、発光部分となる半導体柱と、DBR 反射膜となる半導体壁を制御性良く形成する事が出来る。

【0011】

【実施例】次に本発明の実施例について図面を用いて詳細に説明する。

【0012】図1は、本発明の第1の実施例の面発光レーザの構造を示している。図1(A)は平面図、図1(B)は断面図を示す。図中、1はn型GaAs基板、2はn型DBR 反射膜(n-GaAs/n-AlAs多層膜、厚さは $\lambda/4$ 、 λ は発振光の媒質波長。例えば設

計真空波長980nmの場合には、 $d_{\text{GaAs}} = 69.53\text{nm}$ 、 $d_{\text{AlAs}} = 82.94\text{nm}$ となる。周期数は多いほど反射率が大きくなるが典型的には、15~30周期)、3はn型閉じ込め層(n-AlGaAs、Al組成は0~1、好ましくは0.2~0.5)、4、4aは活性層(InGaAs単一量子井戸、In組成=0.1~0.3、典型的には0.2で厚さ10nm)ここで4aは面発光レーザ本体の活性層を示す、5はp型閉じ込め層(p-AlGaAs、Al組成は0~1、好ましくは0.2~0.5)、6はp型DBR 反射膜(p-GaAs/p-AlAs多層膜、厚さは $\lambda/4$ 、 λ は発振光の媒質波長。例えば設計真空波長980nmの場合には、 $d_{\text{GaAs}} = 69.53\text{nm}$ 、 $d_{\text{AlAs}} = 82.94\text{nm}$ となる。周期数は多いほど反射率が大きくなるが典型的には、15~30周期)、7はp型電極、8はn型電極、9は面発光レーザ本体(幅10 μm 以下、好ましくは0.25~2 μm)、10は半導体壁(ここでは幅 $\sim 3\lambda/4$ 、例えば真空設計波長980nm、実効屈折率3.21の場合には229nm)、11は溝(ここでは幅 $\sim \lambda/4$ 、例えば真空設計波長980nmの場合には245nmとなる)、12は横方向DBR 反射鏡である。ここで、n型閉じ込め層3と活性層4とp型閉じ込め層5を合計した厚みは、 $\lambda/2$ の整数倍とする。例えば、これらの合計厚を λ 、設計真空波長を980nm、活性層4を10厚のIn_{0.2}Ga_{0.8}Asとする場合には、Al_{0.25}Ga_{0.75}Asからなるn型閉じ込め層3及びp型閉じ込め層5は、各々140.5nmとなる。ここでは面発光レーザ本体9や半導体壁10の形状は矩形としている。

【0013】この第1の実施例のレーザ構造においては、面発光レーザ本体9の活性層4aから発生した光は、縦方向(膜厚方向)に対してはn型DBR 反射膜2及びp型DBR 反射膜6が光を閉じ込め、横方向に対しては横方向DBR 反射鏡12が光を閉じ込める構造となっている。縦方向のDBR 反射膜では、反射率はドーピング濃度や周期数で異なる。一例として、周期数20、電子濃度 10^{18}cm^{-3} のn型GaAs/AlAs DBR 反射膜では、反射率の計算値は99.86%である。また、周期数20、正孔濃度 10^{18}cm^{-3} のp型GaAs/AlAs DBR 反射膜では、反射率の計算値は99.77%となる。

【0014】また一方、図1に示すような3周期の横方向のDBR 反射鏡12においては、反射率の計算値は99.90%となる。また、横方向のDBR 反射鏡12が2周期の場合には、反射率98.9%が期待される。このように横方向DBR 反射鏡12では、空気と半導体との屈折率差が大きいため、少ない周期数で大きな反射率が得られる。

【0015】以上に述べたように、本実施例の面発光レーザでは、縦方向及び横方向の両方ともに99%以上の

反射率のDBR反射鏡で囲まれるため、レーザ内部光13は、図1に矢印で示すように効率良く閉じ込められる。このような良好な光の閉じ込めによって光のモード密度が減少し、マイクロキャビティ効果によって、1mA以下の低電流注入領域において、レーザ光に似た鋭い波長スペクトルや放射指向性を持った出力光14が得られる。

【0016】特に、面発光レーザ本体9の幅を、 $\lambda/2$ の非整数倍としておく場合には、波長 λ の光にとって、横方向に発光するモードが少ないため、横方向への自然放出の発光が抑制される。縦方向のモードに対しては、n型閉じ込め層3と活性層4とp型閉じ込め層5の合計の厚さを $\lambda/2$ の整数倍とする事によって、縦方向の発光は共振状態となり促進される。このため、自然放出光の光出力が縦方向のみに集中するため、従来のLED発光と異なって、出力光14の取り出し効率は、10%以上の極めて高い効率が期待される。これに対して、従来のLEDでは、活性層からの光は等方的に放射されるために、光の取り出し効率は高々1%程度と低かった。

【0017】以上述べたような光の閉じ込めの改善の他に、レーザ内部光13に対する呼吸損失低減や、活性層4aに注入されたキャリアの非発光再結合を充分低減する改善を同時に行う事が出来れば、 μ Aオーダーの極めて低い電流領域においても、縦方向へ、自然放出光の集中が起こって、レーザ光に似た鋭い波長スペクトルや放射指向性を有する出力光14を効率よく得る事が出来る。また、さらに電流注入を上げた高電流注入領域では、通常のレーザ発振が得られる。

【0018】次に、第1の実施例の面発光レーザの製造方法について説明する。まず最初に、n型GaAs基板1上に、MBE成長によって、n型DBR反射膜2、n型閉じ込め層3、活性層4、p型閉じ込め層5、p型DBR反射膜6を順次成長する。次にp型DBR反射膜6上にp型電極7を形成する。次に、ドライエッチング法を用いて、溝11を形成する事によって、面発光レーザ本体9と半導体壁10を分離し、横方向DBR反射鏡12を形成する。この場合のドライエッチングとしては、塩素ラジカル及び塩素イオンを反応種とする塩素のECRプラズマを用いた反応性イオンビームエッチング法(RIBE法)や、アルゴンイオンや塩素ガスを反応種とするケミカルアシステッドイオンビームエッチング法(CAIBE法)等を利用する事が出来る。特に、CAIBE法をドライエッチングで用いる場合は、Ni/Au膜をリフトオフ技術でパターニングして、p型電極7を形成した後、このp型電極7のNi/Au膜をCAIBE法によるドライエッチングの際のマスク材として用いる事が出来るため、容易に微細なパターンが形成できる。次に、n型電極8を形成する。最後に、n型GaAs基板1を所望の厚さまで、機械的な研磨によって薄くする。

【0019】図2は、第2の実施例の面発光レーザの断面図である。この実施例のレーザ構造は、ほとんど第1の実施例と同じである。異なる点は、ポリイミド20が、溝11に充填されている点である。第2の実施例では、ポリイミド20によってp側表面が平坦化されるため、引き出し電極21を容易に形成する事が出来る利点がある。また、溝11の幅は、 $\lambda/4$ とするためには、第1の実施例における溝11の幅の(1/ポリイミドの屈折率)とする必要がある。また、第2の実施例の製造方法は、やはり第1の実施例とほとんど同じである。異なる点は、ドライエッチング後、ポリイミド20の塗布および引き出し電極21の開口部やn型電極8の開口部を形成するためのパターニングを行うことである。

【0020】以上の実施例では、活性層を単一量子井戸としたが、これに限らず、多重量子井戸や、20nm以上の厚い活性層を用いても良い。また、n型閉じ込め層とp型閉じ込め層と活性層を合わせた厚さを λ としたが、これに限らず $\lambda/2$ の整数倍ならば、厚さを変更する事が出来る。また、材料として、GaAs/AlAs系材料を用いたが、これに限らず他の半導体材料、例えばInP/InGaAs系材料などを用いる事が出来る。また、第2の実施例では、ポリイミドを用いて、溝を埋め込んだが、これに限らず他の誘電体材料、例えばSiO₂などを用いても良い。また、実施例の平面図では、横方向のDBR反射鏡を四角形で形成したが、これに限らず円形などにしても良い。

【0021】また、実施例では、半導体壁厚を $3\lambda/4$ としたが、これに限らず、 $\lambda/4$ 、 $5\lambda/4$ のなど、一般に $\lambda/4 + (\lambda/2 \text{の整数倍})$ で書き表される厚みならば良い。ただし、 $\lambda/4$ の厚みであると、60nm程度の厚みとなって、半導体壁が倒壊しやすくなる。このような問題がある場合には、図3に示す平面図のように、半導体壁どうしを連結するような補強半導体壁30を設けると良い。また、実施例では、溝11の幅を $\lambda/4$ としたが、これに限らず、一般に $\lambda/4 + (\lambda/2 \text{の整数倍})$ で書き表される幅ならば良い。

【0022】

【発明の効果】本発明によれば、光を縦方向のみならず、横方向にも効率よく閉じ込める事が出来るため、光モード密度を小さくできて、マイクロキャビティ効果によって、低電流域でレーザ光のような鋭い波長スペクトルや指向性を有する出力光が得られる面発光レーザを実現できる。

【図面の簡単な説明】

【図1】本発明の第1の実施例の面発光レーザの平面図(A)と断面図(B)である。

【図2】本発明の第2の実施例の面発光レーザの断面図である。

【図3】本発明の別の実施例の平面図である。

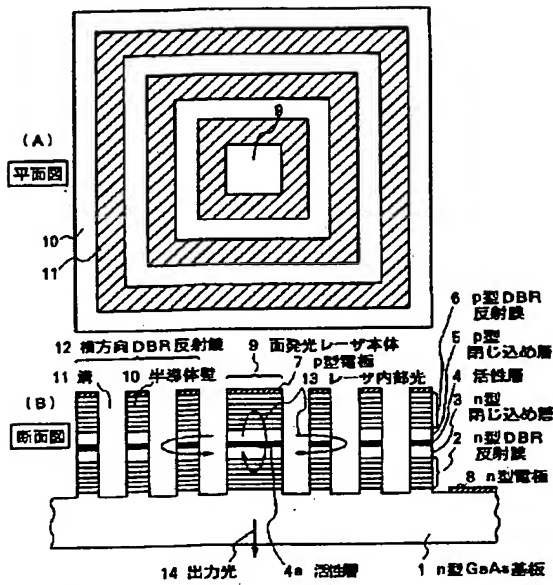
50 【符号の説明】

- 1 n型GaAs基板
2 n型DBR反射膜
3 n型閉じ込め層
4 活性層
5 p型閉じ込め層
6 p型DBR反射膜
7 p型電極
8 n型電極
9 面発光レーザー本体

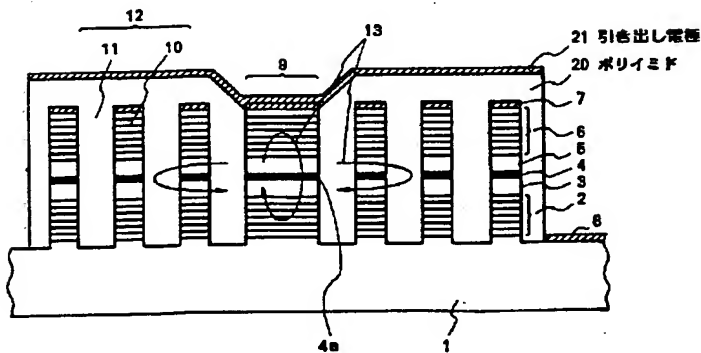
- 10 半導体壁
11 溝
12 横方向DBR反射鏡
13 レーザ内部光
14 出力光
20 ポリイミド
21 引き出し電極
30 補強半導体壁

【図1】

【図3】



【図2】



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